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(56) Documents Cited
GB 2251751 A GB 2247585 A GB 2239366 A
EP 0162713 A2

(58) Field of Search
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INT CL$^5$ F41G 3/22 , G01S 5/16
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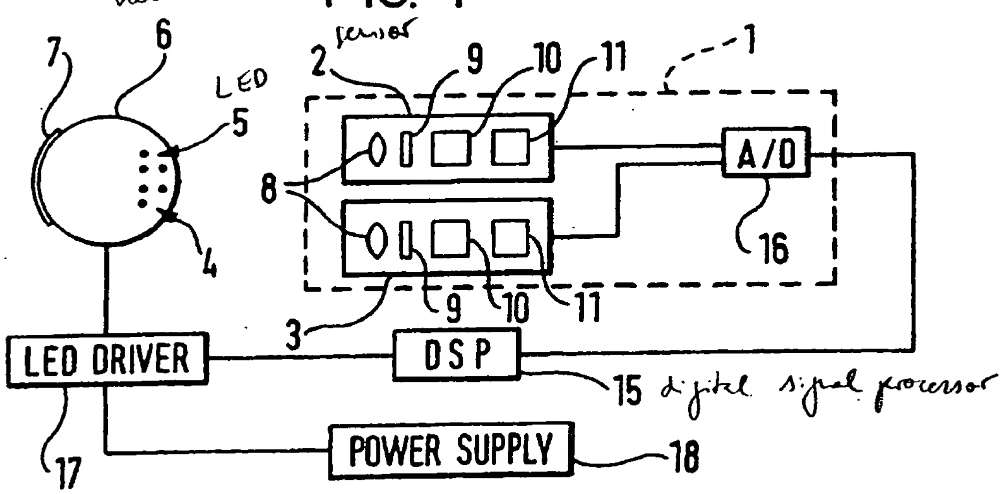
(54) **Optical systems for the remote tracking of the position and/or orientation of an object**

(57) In an optical system for the remote tracking of the position and/or orientation of an object such as a pilot's helmet 6, a light source such as the LED groups 4, 5 on the object are imaged onto photosensitive layers of position-sensitive detectors 10 of sensors 2, 3, the output from the layers depending upon the position of light spots imaged on those layers, the output then being used to track movement of the object. Instead of illuminating the LEDs sequentially as hitherto and then subtracting a reference value corresponding to all LEDs being off i.e. just to background radiation, the LEDs are driven by a periodic waveform and filter means in digital signal processor 15 detects that varying waveform to distinguish the contribution to the output of the position-sensitive detector from the LEDs and from background radiation. The LEDs can now be illuminated simultaneously at different frequencies to provide more accurate location of the object.

FIG. 1




At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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FIG. 1

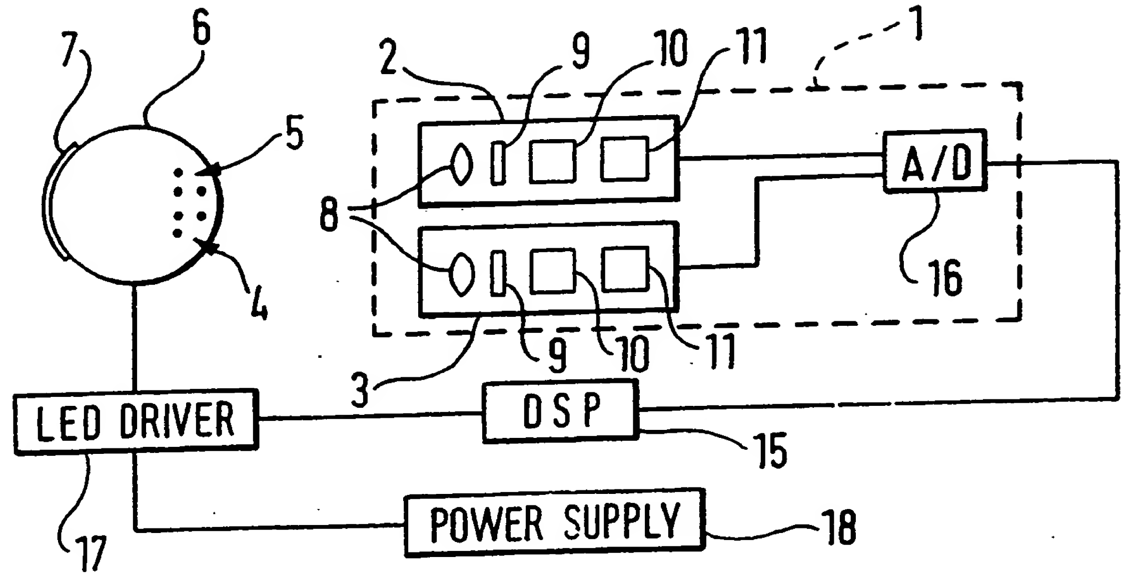



FIG. 2

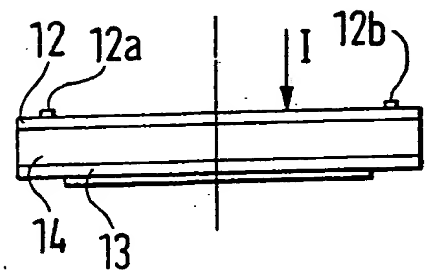
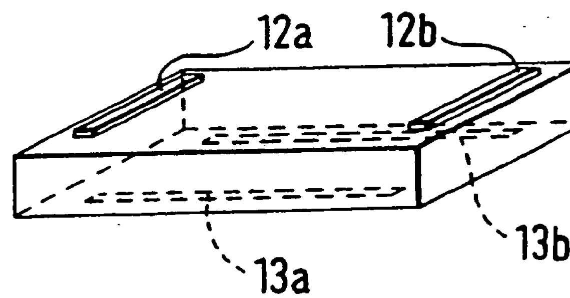



FIG. 3



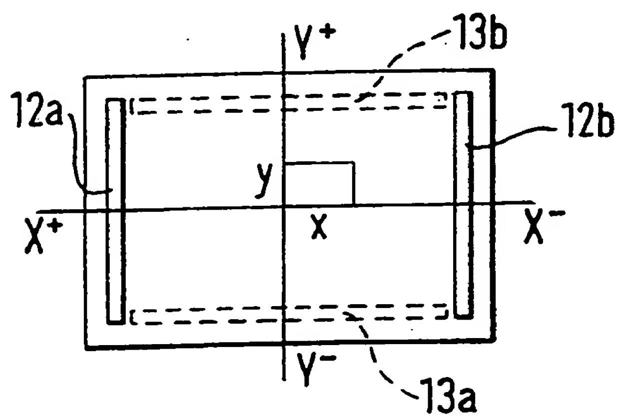




FIG. 4

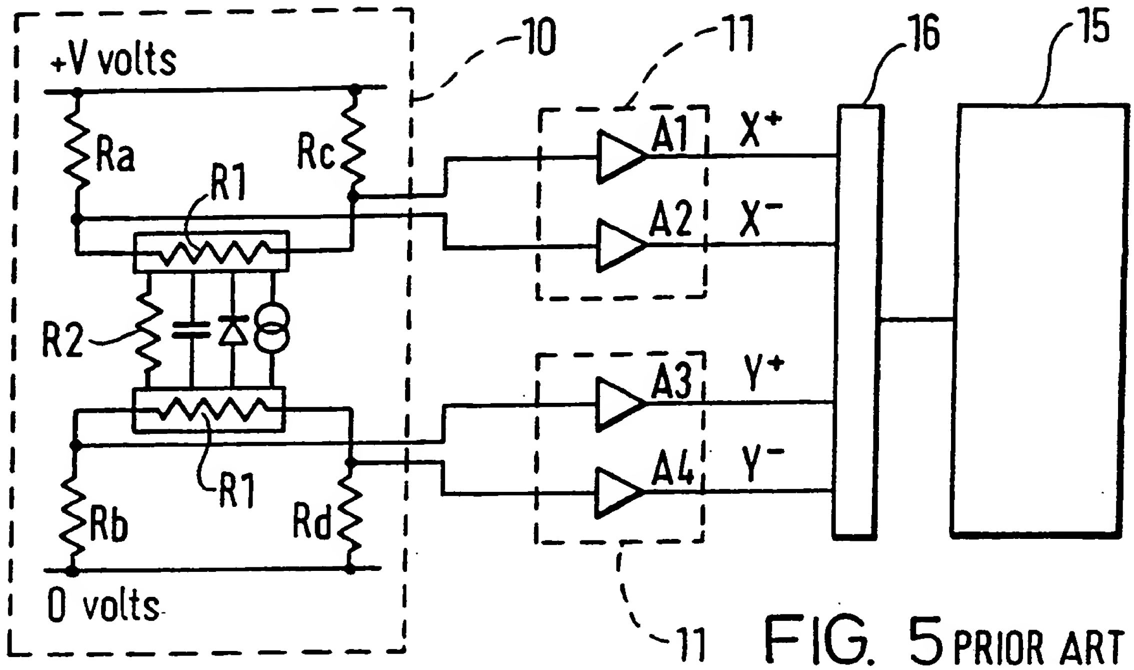
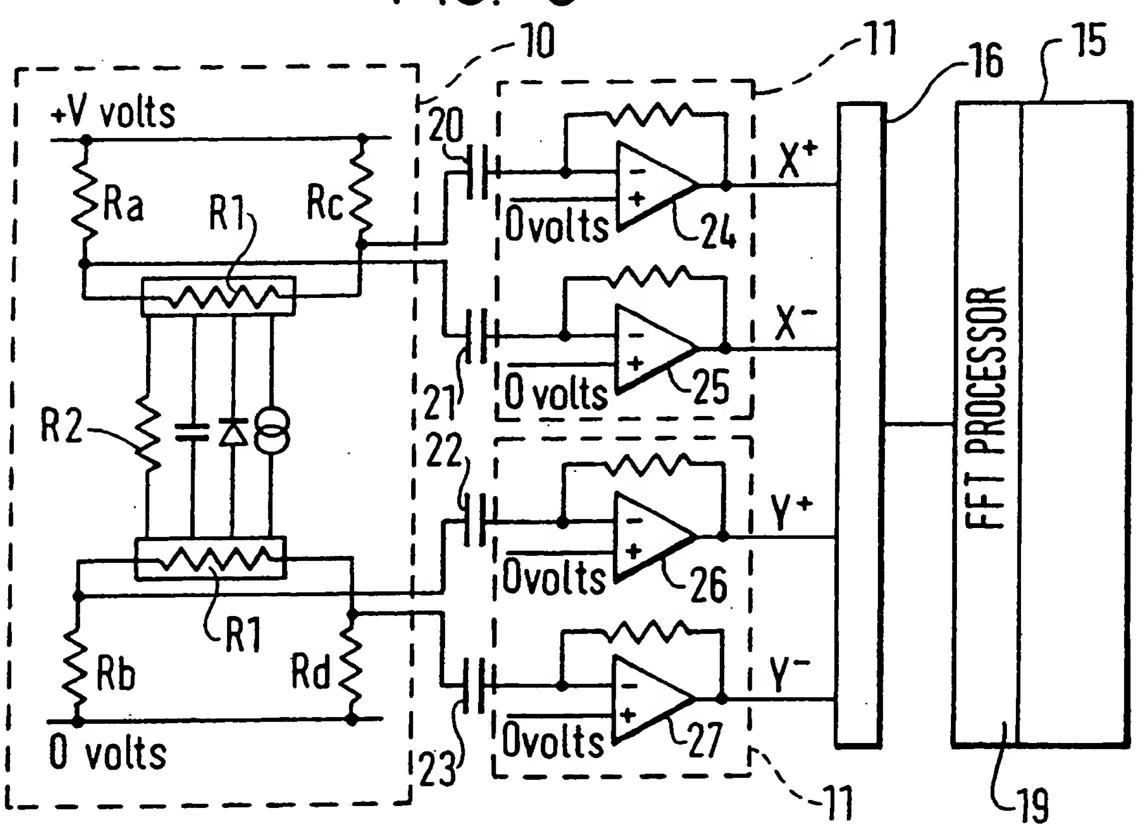



FIG. 5 PRIOR ART

FIG. 6



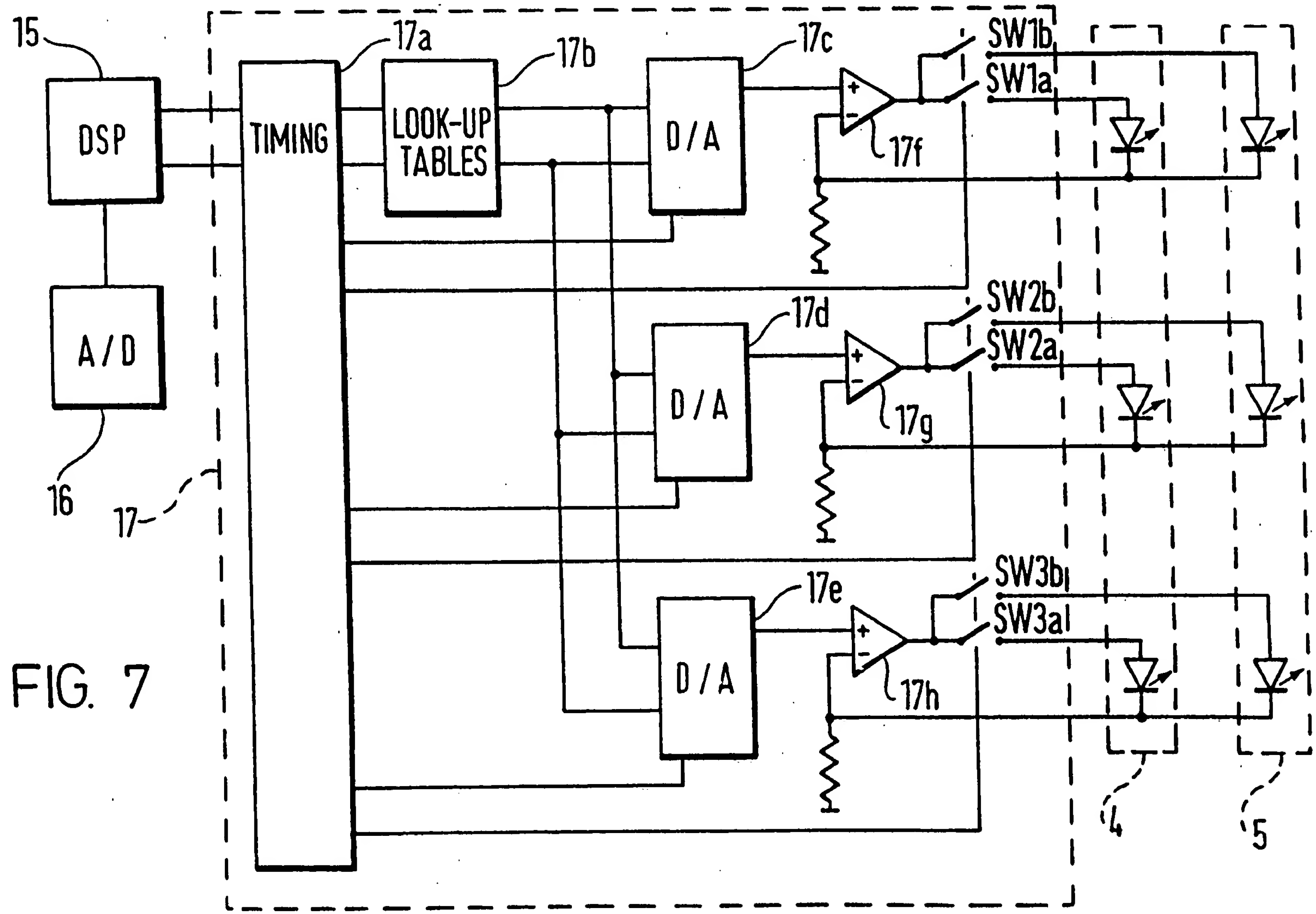

15
DSP
A/D
16
17
17a
TIMING
17b
LOOK-UP TABLES
17c
D/A
17d
D/A
17e
D/A
17f
17g
17h
SW1b
SW1a
SW2b
SW2a
SW3b
SW3a
4
5

FIG. 7

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# OPTICAL SYSTEMS FOR THE REMOTE TRACKING OF THE POSITION AND/OR ORIENTATION OF AN OBJECT

This invention relates to optical systems for the remote tracking of the position and/or orientation of an object.

The invention is particularly concerned with tracking the position and/or orientation of a head-mounted display, for example, a helmet-mounted display, typically in order to register head-up display type symbology on the helmet-mounted display, or to pass the pilot's line-of-sight information to a weapon aiming computer, or to slave steerable sensors e.g. low light TV and infrared cameras to the operator's field of regard. The head-mounted display could instead be for virtual reality applications. However, the invention is more generally applicable to the tracking of the position and/or orientation of any object.

The terms "optical", "light" as used in this patent specification are not intended to be confined to visible light, but are intended to include infrared and ultraviolet wavelengths.

It is known to image light sources mounted on an object onto a position-sensitive detector to accomplish the tracking. In one proposal (EP-A-0 294 101) four LEDs (light-emitting diodes), one of which is positioned outside the plane of the other three, and which are mounted on a pilot's helmet, are simultaneously imaged onto a

CCD sensor. A digital processor computes the position and orientation of the helmet from the position of the four light spots. However, the resolution depends on the number of pixels in the CCD, and this can restrict the accuracy of tracking. Another limitation of CCD sensors is the fact that they have a relatively slow update rate. In another proposal (EP-B-0 162 713), the position-sensitive detector comprises a planar photodiode photosensitive layer, upon which at least three LEDs are imaged in sequence. The signals generated by the position-sensitive detector are related to the position of the respective light spots on the position-sensitive detector, and better resolution can be achieved since the position-sensitive detector is not divided into discrete CCD elements defining the pixels. In another proposal using a planar photodiode photosensitive layer (GB-A-2 251 751), the LEDs are illuminated in sequence by being successively pulsed.

A disadvantage of the tracking systems referred to employing planar photodiode photosensitive layers is that, as far as use in the cockpit of an aircraft for helmet tracking is concerned, sunlight itself can produce a substantial output from the photosensitive layer.

The invention provides an optical system for the remote tracking of the position and/or orientation of an object, comprising a light source mounted on the object, a position-sensitive detector comprising a photosensitive layer arranged to provide output signals dependent on the position of a light spot on the layer, means for imaging the light source onto the layer, to enable the object to be tracked using the

output signals, means for energising the light source so that the intensity of illumination varies periodically in use, and means for filtering signals derived from the output signals to detect the periodic variation of illumination, to distinguish between light on the photosensitive layer from the source and from background radiation.

The periodic variation of the illumination intensity facilitates the detection of light from the light source in the presence of background radiation from sunlight.

Advantageously, there is a capacitive connection between the output of the position-sensitive detector and the filtering means. Such a.c. coupling enables the gain of any amplifier between the position-sensitive detector and the filtering means to be independent of the supply voltage unlike if d.c. coupling was employed. In this way, the steady component of the background radiation is not passed to any such amplifier.

Advantageously, there are at least three light sources on the object and the energising means is arranged to energise them so that the intensity of illumination of each varies periodically at a different frequency. It is then possible to detect the signals from all three light sources simultaneously and to achieve that much better accuracy of tracking in consequence.

The optical system may include four light sources, one of which is out of the plane of the other three, in order to provide unique identification of the position and

orientation of an object with a single position-sensitive detector, although it may be found desirable to provide two or more such sets of four light sources in order to ensure that four light sources are within the field of view of the position-sensitive detector regardless of the position and orientation of the object. However, if two position-sensitive detectors are employed, unique positioning is possible with only three light sources, although again two or more such sets of three light sources may be provided to cover a wider field of view. The light sources are conveniently light-emitting diodes. The photosensitive layer is advantageously a planar photodiode.

An optical system for the remote tracking of the position and/or orientation of a pilot's helmet in a cockpit, constructed in accordance with the invention, will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of the optical system;

Figures 2 to 4 are, respectively, an end view, a perspective view and a plan view of the position-sensitive detector of Figure 1 in more detail;

Figure 5 shows the electrical circuitry associated with the position-sensitive detector of a prior proposal having the same general scheme shown in Figures 1 to 4 as the invention;

Figure 6 shows the electrical circuitry associated with the position-sensitive

detector according to the present invention; and

Figure 7 shows the electrical circuitry associated with light sources mounted on the helmet.

Referring to Figure 1, the optical system comprises an imaging means 1 consisting of two sensors 2, 3, fixed relative to the cockpit of an aircraft (not shown) for tracking sets 4, 5 of three LEDs set into the rear of the pilot's helmet 6. Each LED of each set is imaged by both sensors, and its position in space is determined by triangulation. Unique positioning of each LED set on its own is thus possible, but two sets are provided to allow a greater number of head positions within the cockpit to be tracked, and further sets may be provided for the same reason.

The helmet includes a head-up display on the visor 7 or on a combiner carried by the helmet, which may display symbology highlighting outlines of the surrounding scene, and a weapons system on the plane has its bore-sight aligned with the reticle seen by the pilot projected onto the visor or onto a combiner. The helmet is tracked so that the display can show the correct region of terrain when the pilot turns his head, and also so that the weapons system is swivelled to remain aligned with the reticle (which always appears directly in front of the pilot whichever direction his head is looking in).

To zero the optical system, a reference set of LEDs is aligned with the head-up

display of the aircraft. These LEDs may be mounted on the helmet or on a separate jig.

Each of the two sensors comprises a lens 8, an optical filter 9, a position-sensitive detector 10 and an amplifier 11.

Each position-sensitive detector is a planar photodiode consisting of a p-layer 12 and an n-layer 13 on each side of an intrinsic semi-conductor layer 14 (Figures 2 to 4). A light spot I incident on the position-sensitive detector generates electron hole pairs in relation to the intensity of the spot. The electrons migrate to the n-layer, and the holes to the p-layer. The position-sensitive detector is duolateral and, as such, has one pair of electrodes 12a, 12b on the surface of the p-layer and another pair, extending at right angles to the first pair, on the surface of the n-layer. In the case of the holes generated by the light spot, the resistivity of the p-layer is uniform so, in the case of a light spot off-centre, the resistance from the light spot to one electrode 12a is different to that to the other electrode 12b. Consequently, the injected current is split in the ratio of the resistances, so that the $X^+$ and $X^-$ currents are related to the x-displacement of the light spot from the centre of the photodiode. Similarly, the $Y^+$ and $Y^-$ currents are related to the y-displacement of the light spot from the centre of the photodiode.

The x- and y-displacements are given by the following equations, where L is the side length of a square photodiode:

$$x = \frac{L}{2} \quad \frac{(X^+ - X^-)}{(X^+ + X^-)} \qquad\qquad y = \frac{L}{2} \quad \frac{(Y^+ - Y^-)}{(Y^+ + Y^-)}$$

Each position-sensitive detector is arranged normal to the optical axis of the sensor so that each LED, duly imaged onto the position-sensitive detector, can be tracked as the helmet is moved. The position of the optical axis of each sensor in the cockpit is of course known.

The equivalent circuit of the photodiode is indicated in Figure 5 and Figure 6. It consists of two series resistances $R_1$ and shunt resistance $R_2$ in parallel with the diode and a current generator.

Resistors $R_a$, $R_b$, $R_c$ and $R_d$ provide the necessary reverse bias for the photodiode. The sum and difference currents required for the above equations are calculated in the digital signal processor 15, after each quantity $X^+$, $X^-$, $Y^+$, $Y^-$ are separately digitised in analogue-to-digital converter 16. Digital signal processor 15 also controls unit 17 for driving the LEDs and, like that unit, is powered by power supply 18.

The circuit as described thus far is essentially the same as those of the prior proposals (EP-B-0 162 713, GB-A-2 251 751), in which each LED of each set 4, 5 was illuminated and imaged in turn onto the position-sensitive detectors. The x- and y-

co-ordinates of the corresponding light spots were then calculated and the helmet was tracked accordingly.

There are various disadvantages with the general form of circuit of these prior proposals. For one thing, because each LED of each set is imaged in turn, the true positions of each set may not be recorded, since there may be movement of the helmet between the measuring of the co-ordinates of the respective LEDs. More important, however, is the problem caused by sunlight. Because the signal to be measured i.e. the photocurrent caused by the light spots is a steady value (while the respective LED is illuminated), the amplifiers 11 are d.c. coupled. However, if the amplifiers $A_1$ - $A_4$ were such as to amplify the photocurrents to a little less than one volt, sunlight, which illuminates the whole of the area of the position-sensitive detectors, could result in signals of greater than thirty volts at the output of the amplifiers, even after narrow bandwidth (40 nm) optical filtering of the sunlight. Low-noise amplifiers typically operate from 15 volt supply rails, and would thus be saturated by such signals. To prevent this, the gain of the amplifiers $A_1$ - $A_4$ has to be reduced by a factor of three, reducing the LED induced signal to less than 0.3 volt. The signal to noise ratio which results is relatively poor, and only equivalent to CCD based equipment. Any variation in ambient light between the measurement when an LED is illuminated and the reference background value also causes inaccuracies. A further disadvantage is that an intense LED illumination is required, and the current necessary to produce this illumination can cause EMI problems.

Referring to Figure 6, in accordance with the invention, the LED light sources are illuminated in such a way that the intensity of illumination varies periodically, and signals derived from the output signals from the position-sensitive detector 10 are filtered to distinguish between the contribution to the output signals from the LEDs as opposed to the contribution from the background radiation.

Thus, the LEDs are driven with a periodic, for example, a sinusoidally varying current in LED driver 17, and digital signal processor 15 includes a Fast Fourier Transform (FFT) processor 19. Further, advantage is taken of the periodic control of the LEDs to operate them simultaneously by using different periodic variations of illumination e.g. different sinusoidal frequencies. Also the amplifiers 11 are now a.c. coupled by the interposition of capacitors 20 to 23 between the position-sensitive detector and the amplifiers.

Measurements are made during the first part of an update period, and the positions of the light spots (now sinusoidally varying in intensity and simultaneously present) are calculated during the remainder of the update period. The frequencies of the LEDs are chosen to produce an integral number of cycles during the measurement period. The procedure is repeated in subsequent update periods.

Referring to Figure 7, at the start of each update period, a start command is issued from digital signal processor 15 to timing circuit 17a. The timing circuit sets up a first address in the sinewave look-up tables 17b, and latches the data for D/A

converter 17c. The timing circuit then sets up D/A converters 17d, 17e, and selects LED set 4 or 5 by closing switches SW1a - SW3a or SW1b - SW3b, respectively. The output voltages of D/A converters 17c, 17d, 17e are converted to currents through the respective sets of LEDs 4, 5 selected by amplifiers 17f, 17g, 17h and their respective bias resistors. Next, the timing circuit interrupts digital signal processor 15 to allow the processor to collect data from the A/D converter 16 (corresponding to the outputs of the two position-sensitive detectors resulting from the instantaneous illumination of the LEDs due to the currents through them). Analogue-to-digital converter 16 includes a multiplexed sample and hold, and samples are taken of each of the four channels $X^+$, $X^-$, $Y^+$, $Y^-$ simultaneously. The timing circuit then repeats this cycle for subsequent addresses of the sinewave look-up table, until the required number of data points (typically 128 per channel) are available for use in the FFT processor 19. This will correspond to several cycles of sinusoidally varying voltage supplied to each LED, albeit a different number of whole cycles for each LED.

The capacitors 20 to 23 pass the a.c. signal due to the LEDs and block the d.c. component due to sunlight, of the four outputs of the position-sensitive detector. The amplifiers 24 to 27, being a.c. coupled, may now have a large gain to boost the signal from the LEDs. The output of the amplifier is a composite signal, comprising the three (or four) frequencies due to the LEDs, a small d.c. offset due to the amplifiers, and high frequency noise, with a possible low frequency modulation component due to rapid head movement.

The digital signal processor 15 uses FFT processor 19 to separate the composite signal from each amplifier 24 - 27 into individual LED-generated frequencies, and allows rejection of the d.c. and noise components, improving signal to noise ratio. The amplitudes of the outputs $X^+$, $X^-$, $Y^+$, $Y^-$ are obtained for each frequency, and are then used to determine x, y co-ordinates at the position-sensitive detector for each LED. This enables the position in space of each LED to be detected in digital signal processor 15 during the remainder of the update period, and thus the helmet to be continuously tracked. The output of the digital signal processor 15 is used to control head-up display type symbology on the pilot's helmet-mounted display, and/or to transmit the pilot's line of sight information to a weapon aiming computer, or to steerable sensors e.g. low light TV and infrared cameras slaved to the pilot's line of sight.

Typical values for operation of the optical system are: update period 4 ms; measurement period 2.56 ms; peak value of current for energising LEDs 300 ma; frequencies of illumination of the LEDs (to two decimal places), 2.73, 3.12, 3.52 (and, if four are used, 3.91) $kH_z$; number of samples of each position-sensitive detector output during the measurement period taken by analogue-to-digital converter 16, 128 at a clocking rate of 200 $kH_z$ i.e. 512 samples. This corresponds to seven, eight and nine (and if a fourth LED is used, ten) complete cycles of sinusoidally varying driving voltage for the LEDs respectively for each measurement period.

The invention offers improvements over previous tracking systems by

simultaneous measurement of the LED positions (reducing tracking errors), and operation in high ambient light, due to sunlight rejection circuitry and processing.

Of course, variations are possible without departing from the scope of the invention. Thus, instead of filtering by using an FFT processor 19, digital signal processor 15 could include individual analogue or digital filters tuned to the frequencies to be detected, followed by peak detection/integration over a number of cycles. In low ambient lighting conditions, the amplifiers 24 to 27 could be d.c. coupled, while retaining a.c. LED signals and signal processing. In applications where dynamic tracking errors are less important, each LED could be operated sequentially with a sine signal, using the a.c. circuitry and processing, to improve static accuracy. Also, there is no need for the driving current of the LEDs, or their variation of intensity of illumination, to be sinusoidal: other periodic waveforms e.g. square or triangular waves could be used instead, particularly in the case of sequential illumination. If desired each set of LEDs could include four LEDs, one out of the plane of the other three. One set of four LEDs is sufficient to give exact positioning with one position-sensitive detector. With three LEDs, one set requires two position-sensitive detectors for exact positioning. To provide tracking over as wide an area of the cockpit as possible, several sets of three, or four, LEDs may be provided. However, the sets need not be independent in the sense that some LEDs can be common to more than one set. Finally, while the optical system has been described in relation to helmet tracking in aircraft, it is also applicable to helicopters, or to tracking of any other head-mounted object e.g. a head-mounted display for a virtual reality system, or indeed for

any other object e.g. in robotics. In such cases it may not be necessary for the object to be tracked in all three axes of displacement and all three axes of rotation.

CLAIMS

1. An optical system for the remote tracking of the position and/or orientation of an object, comprising a light source mounted on the object, a position-sensitive detector comprising a photosensitive layer arranged to provide output signals dependent on the position of a light spot on the layer, means for imaging the light source onto the layer, to enable the object to be tracked using the output signals, means for energising the light source so that the intensity of illumination varies periodically in use, and means for filtering signals derived from the output signals to detect the periodic variation of illumination, to distinguish between light on the photosensitive layer from the source and from background radiation.

2. An optical tracking system as claimed in claim 1, in which at least three light sources are provided on an object, and the means to energise the light sources is arranged so that the light sources are illuminated simultaneously and the intensity of illumination varies periodically at different frequencies for the respective light sources.

3. An optical tracking system as claimed in claim 1 or claim 2, in which the filtering means includes an FFT processor.

4. An optical tracking system as claimed in any one of claims 1 to 3, including a capacitive connection between the output of the position-sensitive detector and the filter means.

5. An optical tracking system as claimed in any one of claims 1 to 4, in which the photosensitive layer is a planar photodiode.

6. An optical tracking system as claimed in claim 5 in which the photosensitive layer is rectangular, and two pairs of electrodes extend along the extremes of one pair of edges on one side of the layer and along the extremes of the other pair of edges on the other side of the layer.

7. An optical tracking system as claimed in any one of claims 1 to 6, in which the object is a pilot's helmet.

8. An optical tracking system for the remote tracking of the position and/or orientation of an object substantially as herein described.

9. A method for the remote tracking of the position and/or orientation of an object comprising imaging a light source mounted on the object onto a photosensitive layer of a position-sensitive detector which is arranged to provide output signals dependent on the position of a light spot on the layer, energising the light source so that the intensity of illumination varies periodically, and filtering signals derived from the output signals to detect the periodic variation of illumination to distinguish between light from the source and from background radiation.

**Patents Act 1977**
**'xaminer's report to the Comptroller under ( ction 17 (The Search Report)**

**Application number** 9325510.7

**Relevant Technical fields**

(i) UK Cl (Edition M ) H4D (DLPA, DLPC, DLPX, DLFX & DLAB)

(ii) Int Cl (Edition 5 ) G01S (5/16) F41G (3/22)

**Databases (see over)**

(i) UK Patent Office

(ii) Online database WPI

**Search Examiner**

KEN LONG

**Date of Search**

2 MARCH 1994

Documents considered relevant following a search in respect of claims 1 to 9

| Category (see over) | Identity of document and relevant passages | Relevant to claim(s) |
|---|---|---|
| X,Y | GB 2251751 A (GAERTNER) see particularly page 6 lines 16-17, page 7 lines 22-26, page 8 lines 1-7, page 12 lines 3-7, Claim 1 lines 4-6 and Claim 11 | 1,2,4-7 & 9 |
| Y | GB 2247585 A (AUTOMATIC SYSTEMS) see particularly page 1 lines 1 and 2 and 13 to 20 | 1,2,4-7 & 9 |
| Y | GB 2239366 A (HUGHES) see particularly page 4 lines 15 to 20 | 1,2,4-7 & 9 |
| X,Y | EP 0162713 A2 (CAE ELECTRONICS) see particularly page 4 line 12 to page 5 line 4 and page 5 lines 14 to 17 | 1,2,4-7 & 9 |

| Category | Identity of document and relevant passages | Relevant to clai· ) |
|---|---|---|
| | | |

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